Agilent Technologies

Measuring EDGE Signals – New and Modified Techniques and Measurement Requirements

Application Note 1361

Agilent Technologies
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Introduction

The application of EDGE (enhanced data rates for GSM evolution) technology is gaining significant momentum for new wireless data networks. EDGE promises to allow service providers to deliver theoretical data rates up to 384 kilobits/sec, enabling true third-generation wireless (3G) services such as multimedia and other broadband applications to be offered to mobile customers. EDGE offers important benefits to service providers, including more productive use of the RF spectrum and relatively low upgrade costs for existing systems.

Essentially, EDGE technology is an upgrade to the GSM (global system for mobile communications) standard, providing higher data rates in the same frequency spectrum by using higher-density modulation. The EDGE signal format, which has been adopted as the basis of IS-136HS (interim standard 136), is spectrum-and time-slot compatible with GSM. In other words, both EDGE and GSM signals can be transmitted using the same carrier frequency simultaneously, occupying different timeslots.

The combination of EDGE's new modulation format and different filtering requirements means that systems designers need different methods for measuring the quality of EDGE signals. This application note explores measurement techniques appropriate for analyzing this new signal format, as well as looking at ways to adapt existing GSM measurement techniques. In fact, most GSM measurements can be applied to the EDGE waveform with minor changes.

EDGE and GSM compared

The EDGE and GSM signal spectrums are nearly identical (see figure 1), with the primary difference being that the EDGE signal has deeper nulls at the edges of the main lobe. GSM is a constant-envelope modulation—that is, carrier power does not vary with modulation. While GSM is not as spectrally efficient as some other modulation formats, the constant carrier power allows the use of very efficient power amplifier designs while still avoiding problems with spectral regrowth.

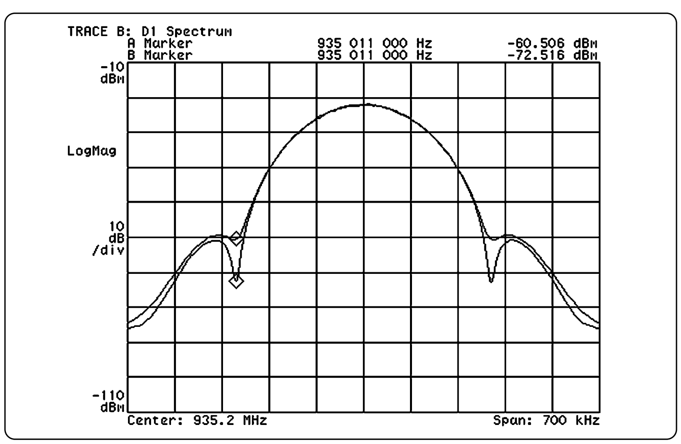

Figure 1. GSM and EDGE signals can typically be distinguished by inspecting the nulls at the edges of the main lobe. As seen in this plot, the EDGE spectrum (bottom trace) exhibits much deeper nulls.

	GSM	EDGE
Modulation	GMSK	$3\pi/8$ 8PSK
Bits/symbol	1	3
Data bits per burst	114	342
Symbol rate	270.833kHz	270.833kHz
Filter	0.3 Gaussian	Linearized Gaussian

Table 1. Representative specifications for GSM and EDGE signal formats.

The EDGE signal has the same spectral characteristics as GSM, as well as the same symbol rate and frame structure (see table 1). To achieve higher data rates, the EDGE signal makes use of both amplitude and phase modulation. The addition of amplitude modulation translates into more stringent requirements for the power amplifier than GSM, as well as a different approach for measuring modulation quality and power.

The amplitude modulation component of the EDGE format results in a much more complex vector diagram (on the right in figure 2). Note that the carrier trajectory, while fluctuating in amplitude, never approaches the origin. The $3\pi/8$ rotation in EDGE, just like the $\pi/4$ rotation in IS-136, is designed to prevent the carrier power from going to zero.

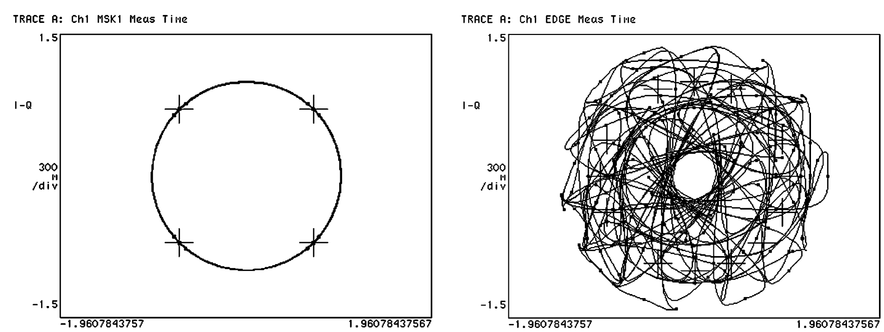

Figure 2. The GSM signal on the left has a constant power envelope, unlike the EDGE signal at right. The plot represents the carrier magnitude and phase at any given point in time. Since the carrier amplitude for GSM is constant, the carrier trajectory forms a perfect circle.

GSM versus EDGE measurement requirements

Since EDGE is spectrum- and timeslot-compatible with GSM, most of the same transmitter measurements are required — some differ only in terms of specified limits. Other measurements, such as output power and power versus time (PvT) require minor modifications to the traditional GSM approach to account for effects of amplitude modulation present in 8-PSK (see table 2).

	GSM	EDGE
Output power over useful part of burst	Not data dependent	Use random data
Spectrum due to modulation	Yes	Different mask
Spectrum due to switching	Yes	Same as GSM
Spurious	Yes	Same as GSM
Power vs. time	Yes	Different mask
Modulation accuracy	Phase error: peak and RMS	EVM: peak, RMS, 95th percentile Origin offset

Table 2. Comparison of representative GSM and EDGE measurement requirements. The data in this table is a snapshot of the draft GSM 05.05 standard and is subject to change.

The only measurement that is significantly different between the two signal formats is modulation accuracy. The critical metric for GSM is phase error, which is assessed by measuring the deviation of the signal's phase trajectory versus the ideal phase trajectory based on the transmitted bits. Limits are placed on RMS and peak phase error. For EDGE, the modulation quality metric is EVM (error vector magnitude). With EDGE, limits are placed on RMS, peak, and 95th percentile EVM. Limits are also placed on origin offset, or carrier feed through for EDGE. And as with IS-136, droop is considered as part of the modulation quality measurement.

GSM/EDGE power-versus-time masks

The amplitude-modulation in the EDGE signal implies varying power during data transmission. This calls for the use of a modified PvT mask for measurements as seen in figure 3. Note in the mask the small regions (2.4dB "gates") at the start and end of the burst through which the carrier envelope must pass. The narrow gates are possible because of carefully chosen tail bits, which produce a precise carrier amplitude trajectory. These gates ensure that the EDGE signal will not droop during the duration of the burst, a behavior that can result from thermal effects in the power amplifier.

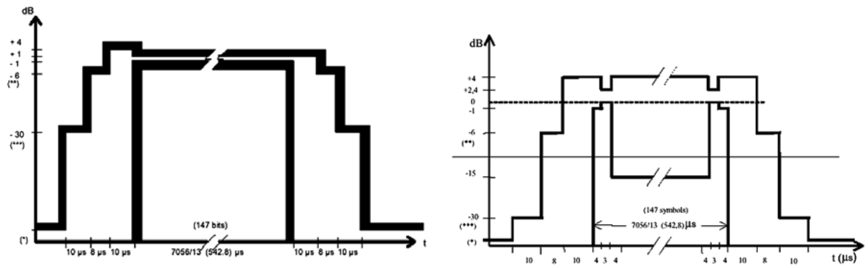

Figure 3. The EDGE signal's amplitude modulation component requires a different power-verses-time mask (right) for measurement than GSM (left).

A number of details are worth noting about the burst shape of EDGE signals (figure 4). For a given timeslot, the tail bits and midamble are constant from burst to burst. Also, the midamble has a lower peak-to-average ratio than data portions of the burst. This is because the midamble symbols are chosen to yield a phase trajectory similar to an MSK signal (GSM), with the intent being that an MSK receiver can then be used to decode the midamble of the 8-PSK EDGE burst. Finally, as seen in the earlier vector diagram (figure 2), the $3\pi/8$ rotation in the EDGE signal prevents the carrier power (which varies due to modulation) from going to zero.

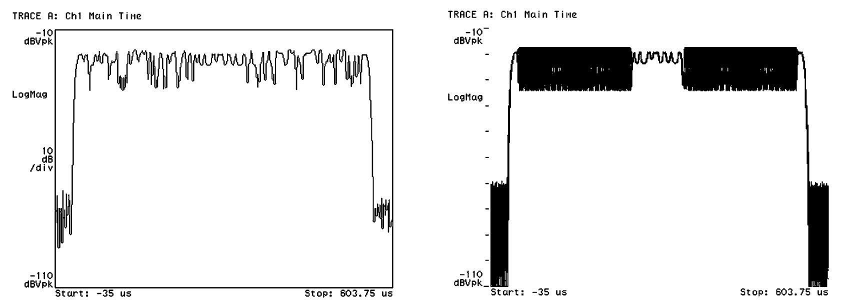

Figure 4. The power vs. time plot at left shows a single EDGE burst, while several hundred bursts are overlaid in the plot at right.

A power-verses-time plot of EDGE and GSM bursts in a single frame reveals their ability to coexist in on the same carrier (figure 5).

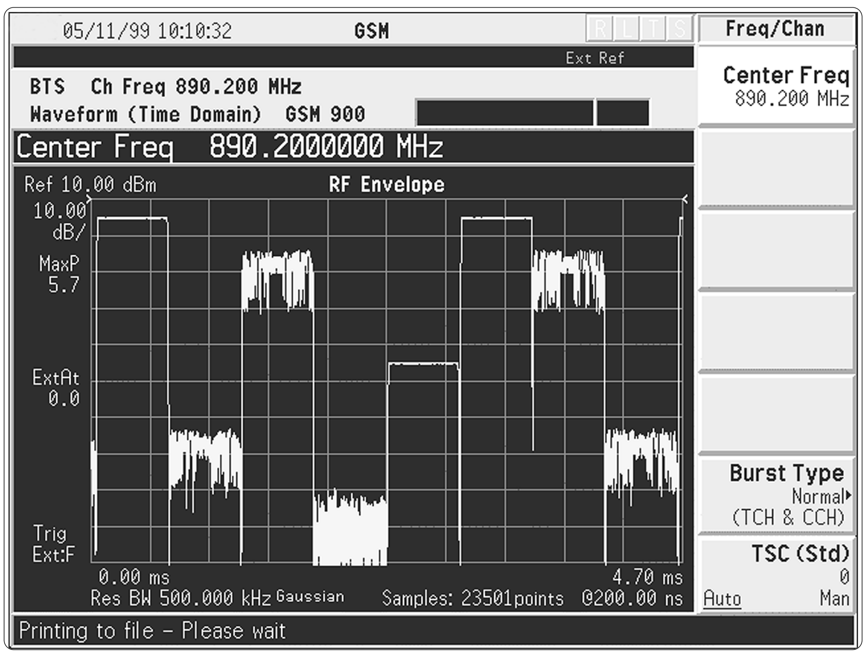

Figure 5. This PvT plot shows both EDGE and GSM bursts in a single frame (plus one empty slot). The signal is generated using two Agilent E4433B ESG series signal generators. One signal generator is used to produce the EDGE bursts at two different power levels. The other generates the GSM bursts, also at different power levels.

EDGE modulation

An examination of IS-136 modulation, the basis of TDMA, can help one gain a better understanding of the EDGE modulation format. EDGE is very similar to IS-136 in concept, with some important differences.

$\pi/4$ DQPSK modulation: similar to EDGE in concept

IS-136 uses $\pi/4$ DQPSK modulation (figures 6 and 7). First, a QPSK constellation is generated from the data symbol stream. The resulting constellation is then rotated by $\pi/4$ radians for each symbol period, producing something similar to an 8-PSK constellation. Finally, the signal is filtered using a root-raised cosine filter, which produces a constellation with a small amount of intersymbol interference (ISI).

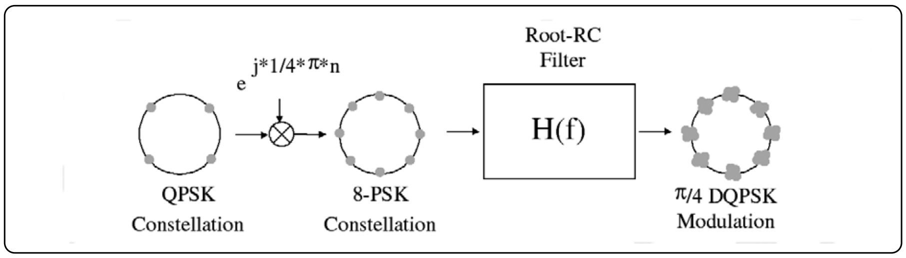

Figure 6. IS-136 TDMA-based systems use $\pi/4$ DQPSK modulation for transmitted signals.

The received IS-136 signal (with ISI) is again passed through a root-raised cosine filter, yielding a zero-ISI signal to recover the 8-PSK waveform. The quality of this signal is easily evaluated by examining the spread of points in the 8-PSK constellation.

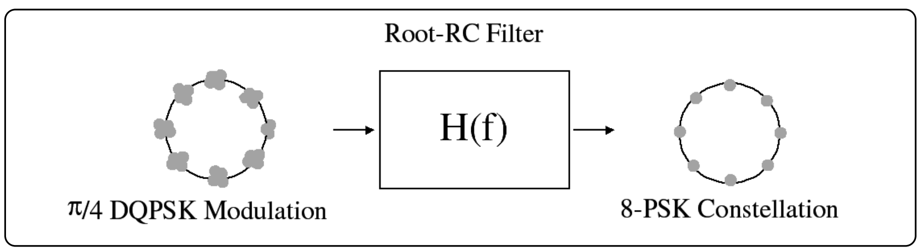

Figure 7. Once received and filtered, the quality of the $\pi/4$ DQPSK modulated signal is easily assessed by looking at the spread of points in the resulting 8-PSK constellation.

EDGE modulation

Instead of starting with a QPSK constellation, the EDGE format specifies that data bits are taken three at a time to produce an 8-PSK constellation. This constellation is then rotated at a rate of $3\pi/8$ radians per symbol interval to produce a 16-PSK constellation. The resulting signal is then passed through a linearized Gaussian filter, which gives the transmitted constellation its “doughnut-with-sprinkles” look as shown in figure 8. This linearized Gaussian filter is designed to produce specific spectral characteristics and creates considerable ISI (see figure 9).

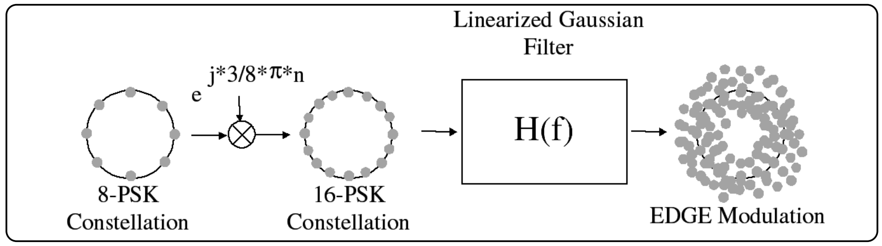

Figure 8. EDGE modulation begins with an 8-PSK constellation, which then undergoes 3π/8 rotation (similar to IS-136 π/4 rotation), and is then filtered using a linearized Gaussian filter before transmission.

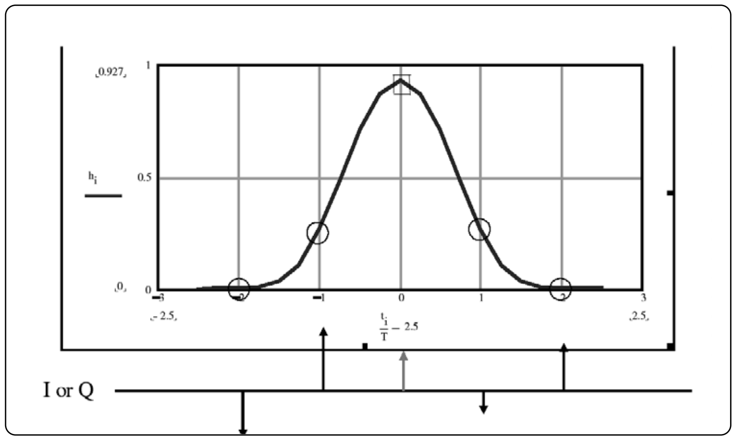

Figure 9. This is a plot of the impulse response of the linearized Gaussian filter. Note that the impulse response is wide enough (long enough in time) that each symbol point in the filtered constellation contains significant contribution from several symbols — the symbol of interest, plus the two symbols at either side.

Filtering the transmitted EDGE constellation

The transmit filter for both IS-136 and EDGE introduces ISI, though not to the same degree. The ISI is of no concern with IS-136 since it is removed by a second root-raised cosine filter in the receiver (or measuring instrument). With EDGE, the transmit filter was chosen for its GSM spectral characteristics. And unlike Nyquist filtered systems, it is not immediately apparent what measurement filter should be used for EDGE measurements.

In most systems, filtering is split between the transmit and receive sections (using matched filters) to provide optimal performance in the presence of noise. Extending this to EDGE, then, one goal of the measurement filter might be to force zero-ISI conditions. This is often referred to as a "zero-forcing" filter (figure 10). However, a zero-forcing filter may not be the best approach for EDGE, as will be demonstrated later.

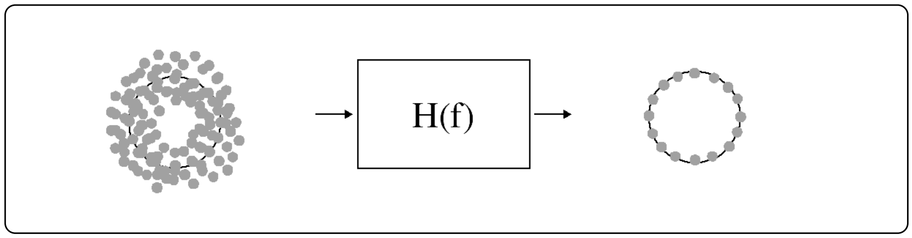

Figure 10. For measuring a received EDGE signal, it would seem that minimizing ISI (and possibly limiting the bandwidth) might be the goal of filtering. This could be accomplished by using a "zero-forcing" measurement filter as shown here.

A number of different zero-forcing filters are suited to removing the ISI and recovering the16-PSK constellation in an EDGE signal. Unfortunately, all of them produce a similar detrimental effect – they force the signal to have a double-sided bandwidth greater than the symbol rate (to satisfy the Nyquist criteria).

Since the EDGE signal has a channel spacing of less than 270.833 kHz, these filters all have increasing gain at frequencies outside of the 200 kHz channel. This gain is necessary to increase the bandwidth of the signal. One such filter is shown in figure 11. Note that the filter gain is almost 12 dB at an offset of 120 kHz, a frequency outside the channel.

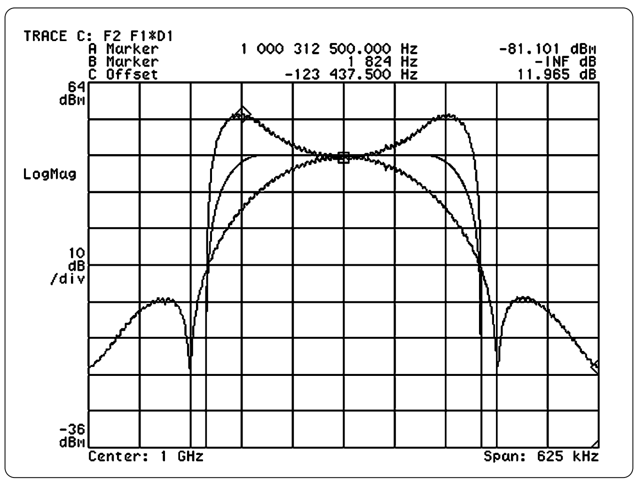

Figure 11. To satisfy the Nyquist criteria and provide a zero-ISI response (middle trace), a zero-forcing or complementary filter (upper-most trace) is applied to the transmitted signal (bottom-most trace).

Problems with zero-forcing filters and EDGE

Two problems emerge when using zero-forcing measurement filters to measure transmitted EDGE signals. The first problem is evident when EVM measurements are made, where errors at frequencies far from the carrier frequency (where the signal energy is low) have a greater effect on measurements than errors at frequencies close to the carrier (where the signal energy is high).

In a typical optimized transmitter-receiver system, the receive filter is designed to closely match the transmit filter so that the effect of noise and spurious signals on the receiver at the low-energy frequencies (typically far from the carrier) are minimized. Thus, with an EDGE signal, a zero-forcing filter is a poor choice for measurement since its spectral characteristics do not match those found in the receiver filter. In fact, the zero-forcing filter actually amplifies noise, distortion, and spurious signals at frequencies where the signal has less energy.

For example, consider a situation where a spurious signal is present at a 10 kHz offset from the carrier, and the result is a specific value for EVM. If the frequency offset of the spur is changed to 100 kHz (with no amplitude change) however, the EVM will be grossly overstated due to the gain effect of the zero-forcing filter.

The second problem with a zero-forcing filter is that it is much wider than the EDGE signal channel. Since practical receiver filters cannot be configured with the same bandwidth as zero-forcing filters, EVM measurements using such filters would be influenced by errors outside the bandwidth of the receiver. EVM measured in this fashion could be a pessimistic predictor of system performance. For example, designers who want to use the minimum amount of backoff in an amplifier could find that EVM is overly sensitive to intermodulation (IM) distortion.

EDGE measurement filters

The first proposed EDGE measurement filter was a raised-cosine filter with noise bandwidth similar to that of a practical receiver. In most systems, such as IS-136, the channel bandwidth is sufficiently wide to enable filtering to eliminate ISI (Nyquist criteria). In contrast, GSM channels are spaced 200 kHz apart, which is less than the symbol rate. Thus with an EDGE signal, the receive filter (or in this case, the measurement filter) does not remove ISI, and actually introduces more.

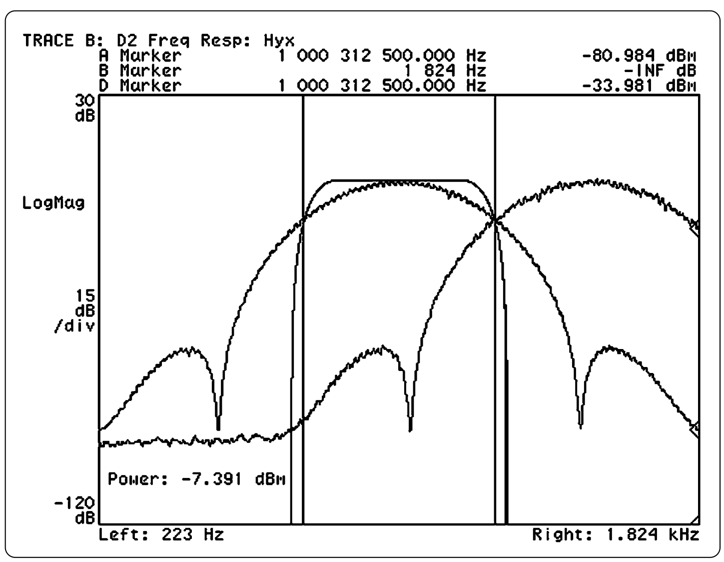

Figure 12. The nearly-centered trace is the first proposed measurement filter, a 90 kHz single-sided bandwidth (180 kHz DSB) raised-cosine filter with an alpha of 0.25. The EDGE symbol rate is 270.833kHz, which is greater than the bandwidth of the measurement filter!

One problem with selecting the 0.25 alpha, raised-cosine filter for EDGE measurement is that the length (in time or symbols) of its impulse response was not considered — only its bandwidth. This means that the error observed in the first few symbols of a burst can be caused by events outside the useful part of the burst. In extreme cases, using the 0.25 alpha, raised-cosine filter as a measurement filter even allows energy from adjacent time slots to introduce error into the useful part of the burst (figure 13).

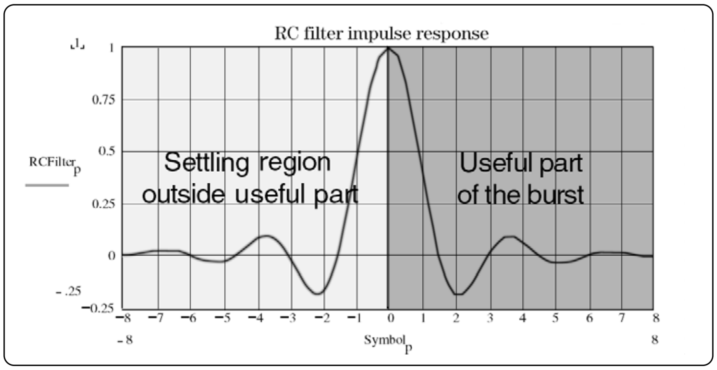

Figure 13. The first proposed 0.25 alpha, raised-cosine filter's impulse response has the potential to introduce errors into the useful part of the signal burst from the settling region, or even from adjacent time slots!

New measurement filter proposed

A proposed modification to the 0.25 alpha, raised-cosine filter for EDGE measurement was offered by engineers at Agilent Technologies, and accepted by industry representatives at a meeting in Amsterdam in December 1999. The new filter is a windowed version of the original, with slightly worse frequency-domain characteristics and a much shorter impulse response length. The windowing (weighting) function was developed to limit the length of the impulse response (figure 14), with minimal impact on the stopband performance of the filter.

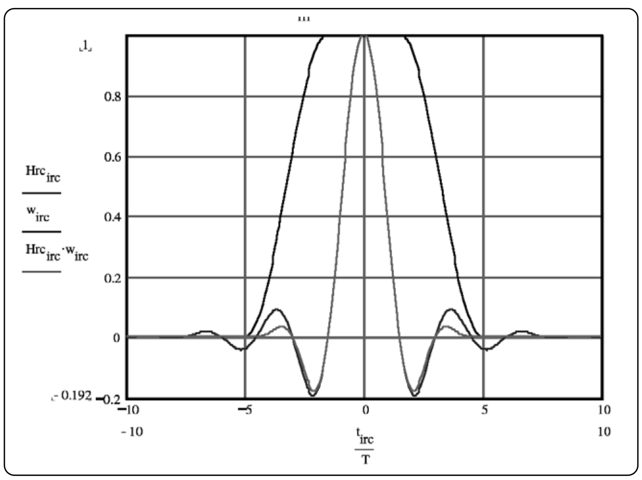

Figure 14. This plot shows the impulse response of the original raised-cosine filter, the windowing function (outer-most trace), and the resulting windowed raised-cosine filter (the more centered trace, closer to zero), which is the product of the first two. The plot reveals significant ringing in the original filter beyond the ± five-symbol interval, while the impulse response of the new filter is zero outside this range.

While the new EDGE windowed-RC filter does not have the same adjacent channel rejection as the RC filter, most EVM measurements are made in the absence of an adjacent channel signal.

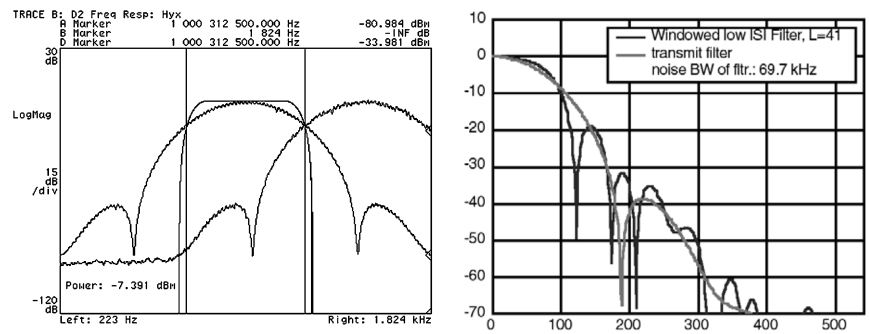

Figure 15. The effects of windowing on the RC filter are clearly visible in these plots. The frequency response of the original filter is shown at left while the windowed version is shown on the right (the darker trace). Note that the sidelobe structure introduced as a result of the windowing causes the response to follow the spectral shape of the EDGE signal.

Analyzing the filtered EDGE signal

Since the new measurement filter has a bandwidth less than the symbol rate, the filter introduces additional ISI. This has the effect of making the raw constellation diagram useless as an indicator of signal quality (figure 16).

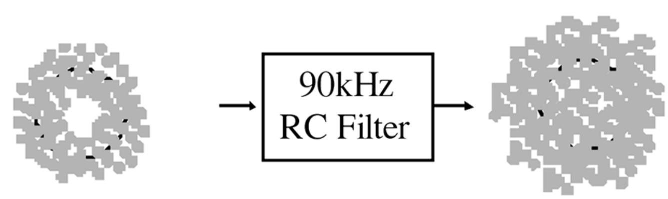

Figure 16. EDGE transmitted constellation, before and after filtering with the “windowed” 90 kHz RC filter.

EVM and the error vector

Even though the filtered constellation looks bad, the EVM modulation quality metric used in EDGE is still valid. Since most systems contain zero ISI, it is tempting to think of the error vector as the distance between a measured constellation point and one of a few ideal constellation points. Consequently, a constellation diagram with a large spread would indicate higher EVM.

Actually, the error vector is the vector difference between the measured and expected carrier magnitude and phase, at the same point in time (figure 17). Thus, EVM remains a valid measure as long as the reference waveform has the same expected ISI as the measured waveform. And this will be the case if the waveform is generated using the same transmit and measurement filters.

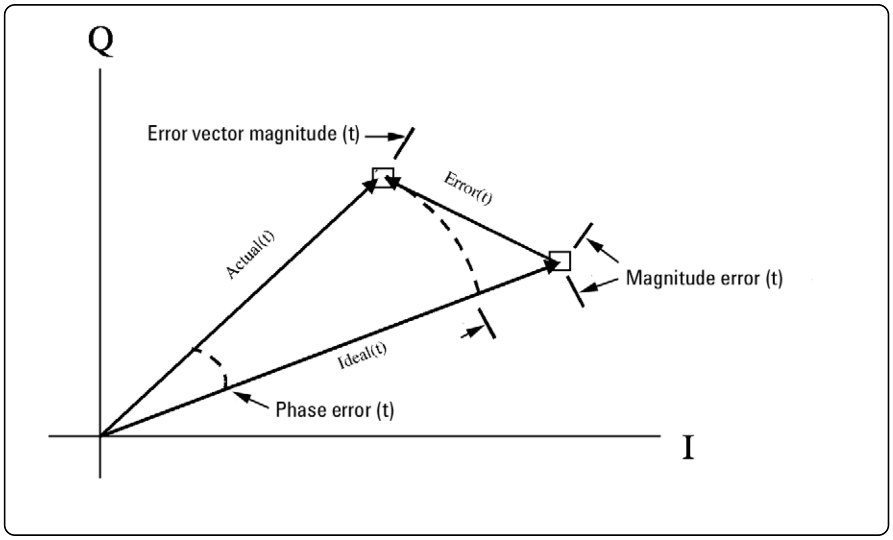

Figure 17. EVM and the error vector defined.

Useful constellations without the distortion of zero-forcing filters

Fortunately zero-forcing or “complimentary” filters are not the only approach to providing measurements with useful constellations. Combining knowledge of the transmitter and measurement filters with the actual symbol sequence, it is possible to compensate for the ISI and to remove it. This operation is performed by Agilent Technologies solutions for EDGE measurements including the 89400 Series Vector Signal Analyzers and the E4406 VSA Series transmitter tester.

Figures 18 and 19 show the result of this ISI compensation process. Compensation is performed on constellation or vector diagrams with a resolution of 1 point per symbol, with symbol transitions represented as straight lines.

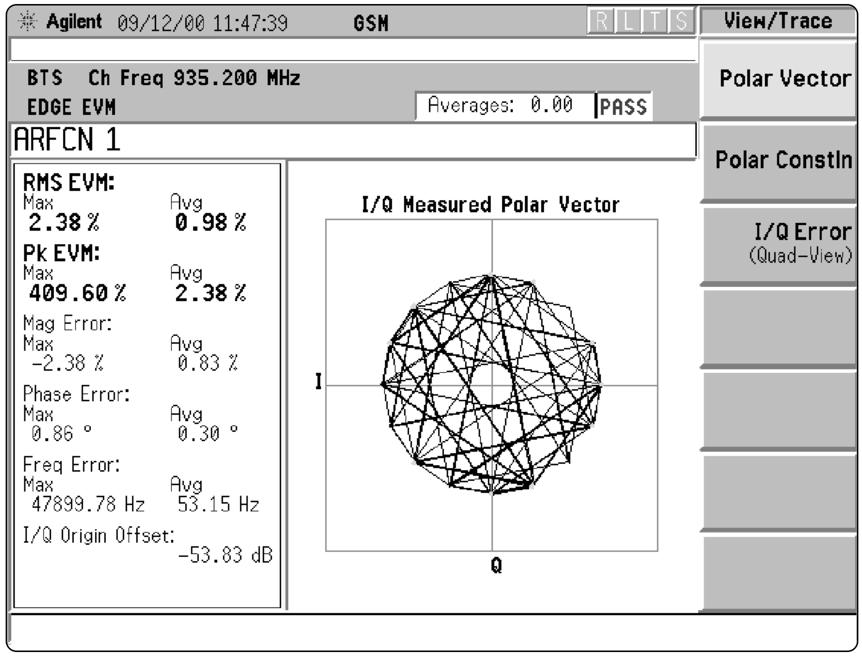

Figure 18. When ISI compensation is applied to an EDGE vector/constellation diagram at 1 point/symbol the confusing effects of ISI are eliminated and a useful constellation is produced without the distortion of zero-forcing or complimentary filters.

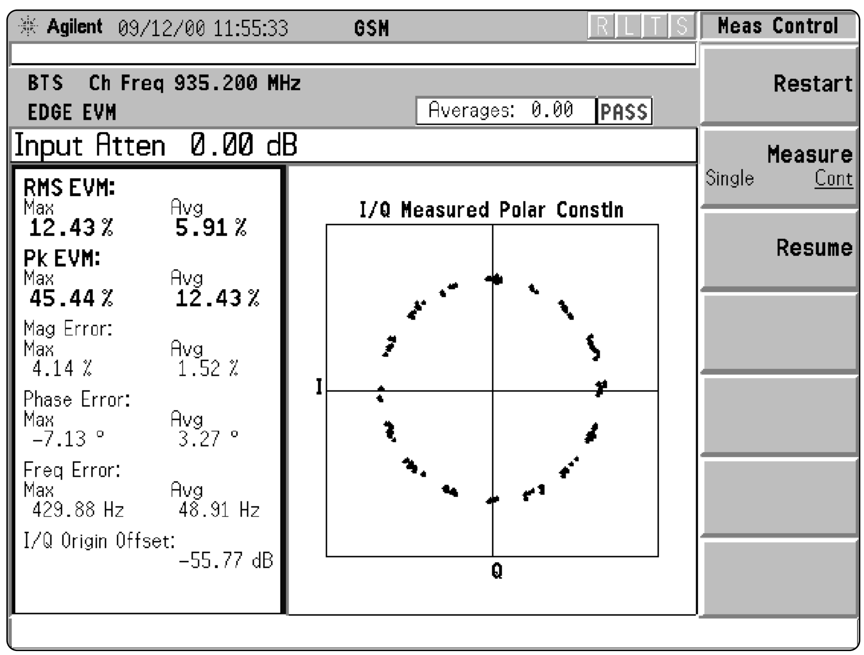

Figure 19. With ISI removed, this constellation diagram clearly shows the presence of undesirable phase modulation or phase noise.

Measurement and test equipment considerations

In selecting test equipment for measuring EDGE signals the application should be considered. Troubleshooting may be more effective if the equipment does not require the midamble or tail bits to adhere to the standard. In addition, identifying impairments is often easier if the effects of ISI have been removed as described above.

The specified measurement filter dramatically limits the signal bandwidth and can make some impairments and errors difficult to diagnose, so instrumentation should allow measurements to be made with this filter removed as well as with the filter in place. Measurements with the filter in place will be necessary to satisfy the requirements of the standard.

Finally, test equipment should take into account the most recent work of the standards committee. For example, definitions for midambles and tail-bit sequences, power vs. time (PvT) masks and the measurement filter have all changed from those first proposed. Therefore, the measurement firmware of any test equipment already owned should be updated to the latest version.

Conclusions

EDGE represents a significant enhancement to GSM. By using a higher-density modulation scheme, EDGE can provide much higher data rates than GSM using the same spectrum. For those faced with developing new EDGE-based systems, some consolation can be found in the fact that most GSM performance measurements can be applied to the EDGE waveform, with few changes. In order to assess modulation quality, EVM must be used instead of phase error for EDGE's 8-PSK signal.

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